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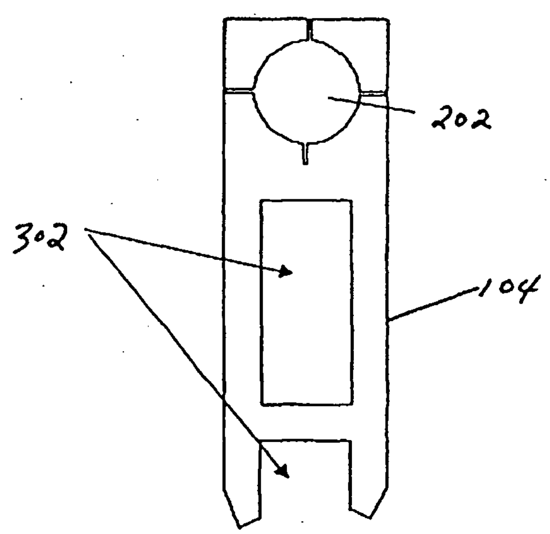
(54) Title: METHOD AND APPARATUS FOR MICROMACHINES, MICROSTRUCTURES, NANOMACHINES AND NANOSTRUCTURES

(57) Abstract: Parts and structures (102) are described for micro and nano machines and the creation of macro structures with nano and micro layers of special materials to provide improved performance.



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METHOD AND APPARATUS FOR MICROMACHINES, MICROSTRUCTURES, NANOMACHINES AND NANOSTRUCTURES

CROSS-REFERENCES TO RELATED APPLICATIONS

[01] This application claims priority from the following provisional application, the entire disclosure of which is incorporated by reference in its entirety for all purposes:

- U.S. Application No. 60/334,181, filed November 28, 2001 by Victor B. Kley for "Cantilever, Nano&Micro Parts, and Diamond Knives."

[02] The following seven U.S. patent applications, including this one, are pending and the disclosure of each other application is incorporated by reference in its entirety for all purposes:

- U.S. Patent Application No.10/094,148, filed 03/07/02 by Victor B. Kley for "Method and Apparatus for Scanning in Scanning Probe Microscopy and Presenting Results;"
- U.S. Patent Application No. 10/093,842, filed 03/07/02 by Victor B. Kley for "Nanomachining Method and Apparatus;"
- U.S. Patent Application No. 10/094,408, filed 03/07/02 by Victor B. Kley for "Active Cantilever for Nanomachining and Metrology."
- U.S. Patent Application No. 10/094,411, filed 03/07/02 by Victor B. Kley for "Methods and Apparatus for Nanolapping;"
- U.S. Patent Application No.10/094,149, filed 03/07/02 by Victor B. Kley for "Low Friction Moving Interfaces in Micromachines and Nanomachines;"
- U.S. Patent Application No. 10/093,947, filed 03/07/02 by Victor B. Kley and Robert T. LoBianco for "Method and Apparatus for Tool and Tip Design for Nanomachining and Measurement;" and
- U.S. Patent Application No. 10/093,947, filed 08/26/02 by Victor B. Kley for "Active Cantilever for Nanomachining and Metrology."

[03] The following U.S. patents are incorporated by reference in their entirety for all purposes:

- U.S. Patent No. 6,144,028, issued 11/07/00 to Victor B. Kley for "Scanning Probe Microscope Assembly and Method for Making Confocal,

Spectrophotometric, Near-Field, and Scanning Probe Measurements and Associated Images;"

- U.S. Patent No. 6,252,226, issued 06/26/01 to Victor B. Kley for "Nanometer Scale Data Storage Device and Associated Positioning System;"
- U.S. Patent No. 6,337,479, issued 01/08/02 to Victor B. Kley for "Object Inspection and/or Modification System and Method;" and
- U.S. Patent No. 6,339,217, issued 01/15/02 to Victor B. Kley for "Scanning Probe Microscope Assembly and Method for Making Confocal, Spectrophotometric, Near-Field, and Scanning Probe Measurements and Associated Images."

[04] The disclosure of the following published PCT application is incorporated by reference in its entirety for all purposes:

- WO 01/03157 (International Publication Date: 1/11/01) based on PCT Application No. PCT/US00/18041, filed 06/30/00 by Victor B. Kley for "Object Inspection and/or Modification System and Method."

BACKGROUND OF THE INVENTION

[05] The present invention relates to micro-electromechanical systems (MEMS) and to Nano Electromechanical Systems (NEMS™). In particular, the present invention is directed to forming parts and structures for micro and nano machines and the creation of macro structures with nano and micro layers of special materials to provide improved performance.

[06] In the foregoing listed related commonly owned issued patents and pending patent applications, various methods, apparatus, and techniques have been disclosed relating to micromachining and nanomachining technology. In U.S. Patent Application No. 10/094,408, various cantilever configurations are discussed, along with possible uses in the fabrication of very small machines. In U.S. Patent Application No. 10/093,842, U.S. Patent Application No. 10/093,947, and U.S. Patent Application No. 10/094,411, tools and techniques for performing micro and nano scale machining operations are discussed. In U.S. Patent Application No.10/094,149, fabrication of MEMS components using diamond as a construction material to substantially eliminate stiction and friction is discussed.

[07] The foregoing are fundamental technologies and techniques that can be used to pave the way to the world of the very small, where structures and machines are measured at micron and nanometer scales. What is needed are improvements to existing tools to facilitate their manufacture and to enhance their performance. There is a need for additional tools to facilitate the creation of ultra-small structures. Techniques and devices are needed for making very small mechanical components and machines such as micro and nano gears, bearings, journals, shafts, cutters, cams, cantilevers, pumps, simple, complex and planetary gear assemblies, latches, locks, calculators, angle drives, propellers, linear motion translators, unique diamond coatings arrangements for knifes and compensatory deformation of target surfaces to use the coating induced stress to create the final form. It is desirable to have useful nanostructures that can be fabricated by these tools which can then serve as building blocks for larger micromachines.

BRIEF SUMMARY OF THE INVENTION

[08] An embodiment of a new smaller and improved cantilever MEMS design in accordance with the present invention is provisioned with features to facilitate the use of cantilever scanning probe microscopy. A cantilever design in accordance with the invention also facilitates the use tools suitable for micro- and nano-scale operations. A mounting plate to overcome present manufacturing limits and improve the overall yields of cantilever assemblies useful for direct nanomachining and metrology is disclosed.

[09] Also disclosed is a geared pump in which the components use properties of diamond and silicon to form a simple high pressure gear pump which is capable of moving fluids from a reservoir chamber to and through very narrow channels and passages. Such a pump overcomes the present limitations of silicon MEMS pumps including their inability to develop high force (pressure) to overcome the Van der Waals and surface forces that inhibit fluid flow in narrow channels and passages.

[10] In accordance with another aspect of the present invention, a diamond coating can be used to impart a desired shape to a substrate. Further in accordance with the invention, certain macro uses of a diamond coating can be applied to general surfaces to produces structures such as micro-scale knives.

BRIEF DESCRIPTION OF THE DRAWINGS

[11] A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings:

Fig. 1 is a schematic representation of a cantilever assembly in accordance with an aspect of the present invention, showing a perspective view and a top view;

Figs. 1A - 1C show variations of bonding channels according to the invention;

Figs. 2 and 2A - 2C show schematic representations of cantilever tip variations in accordance with the present invention;

Figs. 3 and 3A - 3C are schematic representations of variations of the cantilever according to the invention;

Fig. 4 is a schematic representation of a cantilever mounting plate according to the present invention;

Fig. 5 is view of the mounting plate shown in Fig. 4 taken along view line 5-5;

Fig. 6 is a schematic representation of gear pump according to an aspect of the present invention;

Figs. 7A - 7C are additional detailed views of the gear assembly shown in Fig. 6;

Fig. 8 illustrate the general steps for fabricating a knife edge in accordance with an embodiment of the invention;

Fig. 9 schematically illustrates the shaping of a substrate according to the invention; and

Figs 10A and 10B illustrate different knife-edge embodiments.

DETAILED DESCRIPTION OF THE INVENTION

[12] Fig. 1 shows a perspective view and a top view of a cantilever assembly 102. A main body 112 serves as a mounting portion of the cantilever assembly. A flexural member extending from the main body constitutes a cantilever member 104. Recessed features 106 are formed in the main body 112 and serve as bonding channels. In accordance with the invention, the surface area of the cantilever assembly is no greater than three square millimeters (3 mm^2).

[13] The recessed features facilitate mounting the cantilever assembly to an intermediate mounting plate. In a particular aspect of the invention, the recessed features can provide reliable permanent bonding of the cantilever assembly to a larger support structure. Turn to Figs. 1A - 1C for a moment. The views shown in these figures are taken along view line 1-1 in Fig. 1. These views highlight example profiles of the recessed feature 106 according to the invention. In Fig. 1A, a schematic representation of the interior surface 116 of the recessed feature represents a roughened surface. This can be formed by chemical etching or reactive ion etching (RIE) techniques. The roughened surface provides increased surface area and "nooks-and-crannies" to achieve a secure bonding. For example, adhesives or solder or other flowable bonding material can be dispensed within the recessed feature and become securely attach to the roughened surface. This bonding system provides a secure bond without requiring the bonding material be applied past the top surface 114 of the main body 112, thus avoiding interfering with the scanning probe microscopy operations.

[14] Fig. 1B shows another variation of the recessed feature 106. This can be formed lithographically or by other known conventional techniques. The profile shows an opening into the recessed feature that has a dimension (D) smaller than an interior dimension (d) in an interior region 118 of the recessed feature. Fig. 1C shows a similar recessed feature that might have been formed using an isotropic etch process. In both cases the opening dimension (D) is smaller than an interior dimension (d). Stated more generally, in accordance with these particular embodiments of the invention, the opening 120 of the recessed feature at least partially occludes the interior region 118 of the recessed feature.

[15] Returning now to Fig. 1 it can be seen that the recessed features 106 form a contiguous T-shape. It can be appreciated that in other embodiments, discontinuous recessed features can be formed. The particular pattern may be determined depending on the particular structure of the cantilever assembly, or the particular environment of the scanning probe microscopy system.

[16] To complete the discussion of the detail shown in Fig. 1, a lever arm 104 extends from the main body 112. This structure is a flexible member and constitutes the cantilever of the cantilever assembly 102. In one embodiment of the invention, the cantilever is integral with the main body. For example, the cantilever assembly can be fabricated from a silicon on insulator (SOI) wafer. The cantilever 104 can be a lithographically defined structure. It can be appreciated, however, that the cantilever can

be a separately fabricated member that is subsequently attached to the main body during manufacture.

[17] Fig. 2 schematically illustrates a cantilever 104 in accordance with an aspect of the invention. A recessed region 202 is formed into a major surface 214a of the cantilever in an end portion of the cantilever distal the main body 112. The recessed region can be used to as a receptacle or mount point for receiving a secondary object. As can be seen in the profile view of Fig. 2A, for example, the recessed region is shown as a bowl-shaped recess. However, such shape is not necessary. The recess can be formed to take on a shape that is suitable for a particular implementation.

[18] The recessed region illustrated in Fig. 2 is shown with a circular-shaped outline. However, it can be appreciated that other outline shapes might be more suitable for attachment of a secondary object. The shape can be a substantially continuous form; e.g., elliptical, ovoid, etc. The shape can be triangular, quadrangular, pentagonal, and in general any regular or irregular polygonal shape.

[19] To facilitate the attachment of a secondary object, one or more alignment features can be formed on the surface 214a. For example, Fig. 2 shows four such alignment features 204a - 204d, though additional or fewer features can be provided if appropriate. The side views shown in Figs. 2A - 2C illustrate that the features can be recessed features or raised features. For example, Fig. 2A shows that the features 204b - 204d are raised surface features. These can be formed, for example, by properly masking the surface of the cantilever 104 and etching away a layer of the surface, leaving only the raised features 204b - 204d and revealing the surface 214a. Fig. 2B shows that the alignment features 204b - 204d can be recessed features. Fig. 2C shows a mixture of raised features 204b, 204d, and recessed features 204c, illustrating that any combination of raised or recessed alignment features can be formed, if needed. Fig. 2C also shows a suitably formed through hole 222 which can further facilitate attachment of a secondary object.

[20] Fig. 3 shows a cantilever exemplar according to another aspect of the present invention. The cantilever 104 may have a series of etched through passages sufficiently large to ventilate the cantilever and thus permit easy flow of air or other gases through the cantilever. One or more perforations 302 or openings can be formed through the cantilever. The number, size, shape, and arrangement of openings can vary, depending on the requirements. For example, increasing the air flow by use of this ventilation scheme can reduce the total air resistance can and thus improve the Q or signal to noise ratio of

the cantilever when used in resonant SPM scan such as non-contact scanning, intermittent contact scanning, or tapping mode scanning operations. Openings can be used to attain a desired flexibility (spring constant) in the cantilever. The openings may serve to reduce the mass of the cantilever, and so on. This cantilever design can improve signal to noise when certain Scanning Probe Microscopy methods are used in conjunction with the cantilever such as resonant non-contact Atomic Force Microscopy, Lateral Force Microscopy, and Magnetic Force Microscopy.

[21] Fig. 3A shows an opening formed through the major surfaces 214a and 214b of the cantilever. Fig. 3B shows that the first opening 302' can be out of alignment with respect to the second opening 302", if a particular need requires for such a configuration. Incidentally, Fig. 3A shows another mixed combination of raised and recessed alignment features 204b - 204d.

[22] Perforations 302 can be formed such that the cantilever possesses a lattice structure. Fig .3C shows various cantilever structures 104a, 104b, 104c having varying patterns of openings 312, 322, 332, respectively. These cantilever exemplars illustrate that any pattern of perforations can be provided to accommodate particular structural or operating characteristics of the cantilever.

[23] Incidentally, Fig. 3C shows alternative configurations of recessed regions and alignment features. Recessed regions 302 can be any shape; for example, the figure shows a elongate shaped recessed region and a diamond shaped recessed region. The recessed region can be off-center or not. The figure shows a square-shaped through hole 322 as an example. The alignment features 322 can be asymmetrically arranged, or may not even be required. It can be appreciated from the various illustrated exemplars any configuration of recessed regions and alignment features can be provided to accommodate a particular application.

[24] Cantilever assemblies 102 can be fabricated on different sized wafers. The larger wafers tend to be thicker than smaller wafers. Standard wafer sizes include 4, 6, 8, and 12 inch wafers, although non-standard wafers could be used. A larger wafer allows for higher production yields of cantilever assemblies. Cantilever assemblies with large dimensions may require a thicker substrate than a smaller sized cantilever assembly, thus requiring the use of thicker wafers. The result is a range of thickness dimensions when a family of cantilever assemblies are manufactured to accommodate different uses.

[25] Fig. 4 shows a mounting plate 402 having a compensating recessed region 412 formed in the plate. The compensating recessed region can be configured to

accommodate dimensional differences among cantilever assemblies and by so doing can maintain a pre-selected positioning of the cantilever, measured for example from the backside of a cantilever relative to a reference.

[26] Figs. 5A - 5C show sectional views of the mounting plate 402 taken along view line 5-5 in Fig. 4. A cantilever assembly (not shown) can be mounted on a principal surface 502 of the mounting plate. However, in accordance with the invention, a recess is formed with a plurality of interior surfaces, e.g., surfaces 504, 506, and 508, configured to receive cantilever assemblies of varying dimensions. These surfaces comprise the compensating recessed region 412 of the mounting plate. The dimensions W_1, H_1 and W_2, H_2 of the receiving regions defined by the surface can be determined depending on the range of dimensions of the cantilever assemblies to be accommodated by the mounting plate.

[27] For example, Fig. 5B shows a cantilever assembly 102a shown received in the region partially defined by surfaces 506, 508 of the mounting plate 402. The backside 214b of the cantilever 104 is measured relative to a reference surface, R. Typically, the measurement is made relative to a surface to be scanned. As a matter of convention the direction of the measurement can be considered to be in the Z-direction. The distance is shown as Z_0. Fig. 5C shows a second cantilever assembly 102b having different dimensions. The region partially delimited by surfaces 504 has an appropriate width dimension to receive the larger cantilever. Moreover, the depth dimension (H_1) is such that the backside 214b of the cantilever 104b has a Z-direction measurement of Z_0.

[28] Thus in operation, the body dimensions of a cantilever assembly can be chosen along with the dimensions of a recess in the mounting plate 402 to place the back side of the cantilever in the same plane (relative to the Z-direction) regardless of its overall part thickness without affecting the overall operation of the entire instrument. It can be appreciated further that in addition to variations in part thickness among cantilever assemblies, variations in the Z-direction position of the cantilever 104 relative to its main body 112 among cantilever assemblies can be compensated for in the same manner by properly adjusting the Z-direction dimension (H) of the corresponding receiving region. Thus, standard wafer thicknesses such as 525 microns, 625 microns etc. can be accommodated without affecting the interchangeability of the instrument. It can also be appreciated that non-flat surfaces appropriately configured and dimensioned can be used instead of or in combination with the flat surface exemplars shown in Figs. 5A - 5C.

[29] Fig. 6 schematically represents an illustrative embodiment of a high pressure gear pump MEMS according to an aspect of the present invention. A gear drive assembly 600 provides a driving force to actuate gears in a gear box assembly 612. In the particular embodiment shown in the figure, the gear drive exemplar includes a translation section comprising a plurality of expanding members 602 arranged in a lattice-like structure. A gear rack 604 is provided at a distal end of the lattice structure.

[30] In a particular embodiment of the invention, the fabrication of the gear drive 600 can be fabricated as disclosed in pending U.S. Patent Application No. 10/094,408. Briefly, the gear drive can be formed on a silicon on insulator (SOI) wafer. The upper surfaces 600a and 600c are the silicon layer spaced apart by a layer of insulation (not shown) from an underlying substrate 600b. The lattice structure can be defined photolithographically. An isotropic etch process applied in the regions of the expanding members 602 can remove the underlying insulation layer thus creating a suspended lattice structure fixed at a region A. The silicon layer is partitioned into two zones 600a and 600c. A ground potential can be applied to one zone (e.g., 600c) and a voltage source V can be applied to the other zone (e.g., 600a). A return path segment of silicon 606 provides a return path for electric current to complete the electrical circuit from the voltage source V to ground. The flow of current will cause thermal expansion of the translation section (expanding members 602) due to heat generated by the flowing current. The expansion will occur in all directions, however, the geometry of the lattice structure will produce a more pronounced expansion in the direction along arrow 622. Removing the current will cause the translation section to contract as cooling occurs, again along the direction of arrow 622. Repeated application and removal of current can produce a reciprocal motion 622 of the gear rack 604.

[31] A pump room 632 houses a gear assembly 612. The gear rack 604 engages the gear assembly to drive the gears (Fig. 7A) by the reciprocating motion 622 of the translation section. A fluid reservoir 616 provides a source of fluid which can be pumped through a suitably formed orifice 614 in the direction F. Fluid can be provided from an external source to the reservoir through an inlet 618. Fig. 6 represents the orifice 614 in schematic fashion, illustrating the principle of the fluid pump. It can be appreciated that a suitable connection or channel can be provided to deliver the pumped fluid to a destination.

[32] Fig. 7A shows a cutaway view of the pump room 632 view in the direction of view line 7-7 shown in Fig. 6. A pump casing 712 houses the gear assembly 612 in a

pump chamber 714. This views shows a portion of zone 600c of the silicon layer. The gear assembly comprise a first gear 702a and a driven gear 702b in mesh with the first gear. Each gear has a gear shaft 704a and 704b, respectively which is supported on bearing journals 716 formed on the silicon layer 600c. The gear rack 604 is shown engaging the driven gear. The reciprocating motion 622 will cause the gears to rotate in a reciprocating fashion. To complete the description of the figure, the return path segment 606 is shown. The areas of contact where the gears mesh form high pressure points, thus defining a high pressure area 722 in that region.

[33] Fig. 7B shows a cutaway view of the pump room 632 seen from the top. It can be seen that portions of material in zone 600a and zone 600c of the silicon layer serve as journal bearings 716 on which the gear shafts 704a and 704b are supported. The journal bearings can be round or cylindrically shaped bearing surface, or V-shaped surfaces (e.g., 55° V-shapes). The gears 702a and 702b are placed on the journals within the pump chamber 714 of the pump room, allowing the gears to turn multiple revolutions or less then one revolution, depending on the stroke length of the gear rack 604. In an particular embodiment, the gears can be inserted into journals formed in the pump chamber. The pump casing 712 can be provisioned with opposing journals and a suitable channel to direct the high pressure flow can be placed over the pump chamber. It can be appreciated, however, that many other arrangements are possible.

[34] From the top view, it can be seen that the chamber is in fluid connection with the reservoir 616. Walls 714a and 714b of the chamber 714 are closely spaced from the faces 706a, 706b respectively of gears 702a and 702b, leaving substantially only the gear teeth being exposed to the interior volume of the chamber. A channel 724 fluidically couples an opening 724 in the chamber 714 to the orifice 614. The channel in a given particular embodiment can be directed as appropriate to some other suitable structure or destination. The channel can be about 50 microns to 1 nanometer in width.

[35] Fluid from the reservoir is picked up by the gear teeth when the gears rotate. The fluid is forced by the action of the gear teeth into the high pressure area 722. The channel 724 is aligned with respect to the high pressure area allowing the high fluid pressure present to escape via the channel 724. The constrained spacing between the chamber walls 714a, 714b and the gear faces 706a, 706b creates a region of high flow resistance, thus preventing significant flow of fluid back into the chamber from the high pressure region and ensuring a flow of fluid through the channel. It can be appreciated that the chamber walls do not have to extend across the entire face of the gears. In the

case of a pump, it is sufficient that a region about the chamber opening 724 is sufficiently covered as to restrict the flow fluid from the chamber opening back to the reservoir 714.

[36] Referring to Figs. 6 and 7A, it another aspect of the invention an escape mechanism (not shown) can be employed to selectively disengage the gear rack 604 from the gear assembly 612, for example, by moving the rack up and down (arrow 624). Thus, for example, the gear rack can be engaged during the forward (or reverse) stroke of the reciprocal motion and the disengaged during the reverse (or forward) stroke. This would cause each gear to rotate continuously in one direction. However, in the currently shown embodiment, the pump can be effective from just the back and forth rolling of the gears when no such escape mechanism is used. Also it can be appreciated that alternate drive mechanisms other than the described thermal mechanism can be used to drive the gear assembly. For example, a suitable electrostatic comb drive, a piezoelectric drive, or a piezoresistive drive, a rotating electrostatic motor, and other similar devices can be used. Incorporating an escape mechanism to produce unidirectional gear rotation, however, can be useful in other applications.

[37] Fig. 7C shows additional detail of the gears 702a and 702b comprising the gear assembly 612. In accordance with a particular embodiment of the invention, the gears are made of an obdurate low stiction material 752 (like diamond) interacting with another similar material or with silicon. In the particular embodiment shown, each gear 732, 734 can be a diamond gear with integral shaft 732a, 732b fabricated using nanolapping diamond coating techniques more fully discussed in pending U.S. Patent Application No. 10/094,411 and in U.S. Patent Application No.10/094,149. In accordance with the invention, each gear has a maximum surface area less than 1 mm^2.

[38] A diamond coating can also be provided onto a substrate to form tools. The generalized fabrication sequence shown in Fig. 8 diagrammatically illustrates a substrate 802 having a coating of diamond 812 formed thereon. The substrate material can be titanium (or some tungsten-based compound), titanium aluminum vanadium (or some other titanium-based compound), silicon, tungsten or any very low cobalt metal ceramic carbide or nitride. The diamond coating can have a thickness of 1 - 20 microns. An overcoat coating 804 can be provided on the diamond coating. The overcoat coating can be titanium or tungsten followed by an optional bonding layer 822 (indicated by phantom lines) such as nickel and an optional companion substrate of (typically) titanium 824 (also indicated by phantom lines).

[39] A diamond edge can be formed by performing a sharpening operation on the layered structure. As the tough matrix material of metal(s) and/or ceramic(s) is removed during the sharpening process the thin hard diamond film, which is already sufficiently thin as to be very sharp, is exposed for the cutting operation. The resulting diamond edge can then serve as the leading surface used in a cutting operation. The quality and sharpness of an edge depends on its hardness. The diamond layer provides the material to present a superhard edge supported by a robust matrix of tough metal(s) and/or ceramic(s), as indicated above.

[40] Referring to Figs. 10A and 10B for a moment, the resulting sandwich can result in two kinds of knife. A first knife assembly 1052 illustrated in Fig. 10A comprises a diamond layer 1014 forming a very thin blade having a sharp edge by virtue of the diamond layer being thin. The diamond edge can be covered by a thin (1 to 3 micron) layer of titanium and/or tungsten.

[41] Alternatively, a second knife assembly 1054 shown in Fig. 10B comprises an optional thick substrate 1024 which can be glued or thermally bonded to the over coated titanium and nickel layer to form a rugged cutting edge with the diamond layer 1034. In this particular embodiment, the diamond layer is rigidly protected in the middle of the knife assembly by the metal layers. However, the metal must be carefully sharpened and shaped to insure that the diamond is properly exposed to serve as a superhard edge.

[42] Returning to Fig. 8, if the coated substrate 802 is too thin the diamond film may through shrinkage (or expansion) induce a warping effect on the substrate. The substrate can be preformed to exhibit a complementary warped shape in order to compensate for the expected the warpage due to the diamond layer. Alternatively, the substrate can be coated on the back of the side to provide a reverse warping effect (bending forces in the opposite direction) and then coated with titanium or tungsten.

[43] Depending on the coating material and its expansion coefficient with respect to the surface to be coated, it is possible to selectively produce either an expansion induced warp or a contraction induced warp. For example, suppose a non-expanding or low-expansion rate glass is coated onto a high expansion piece of copper at an elevated temperature T_A. Then as the system cools, the contracting copper will compress the glass and may bend or shatter it. If the glass bond and the glass is weak enough (thin enough) and the copper relative to the glass is strong or thick enough, the glass may curve its edges inward toward the copper center. In the case of diamond on silicon, a very thin layer diamond (for example, a diamond layer a hundred times thinner than the silicon

substrate) can cause bending of the silicon toward the center of the diamond layer as the materials cool, due to different coefficients of expansion of diamond and silicon, and due to the very high molecular bond strength diamond as compared to the bond strength of silicon.

[44] Fig. 9 schematically illustrates this aspect of the invention with a generic "pre-shaped" substrate that is suitable for deposition of a diamond layer to produce a desired shape (or surface contour) while taking into account the thermal cooling induced warping effect of diamond layer. A starting substrate material 902 can be formed to possess a predefined shape or surface contour. It can be understood that the pre-shaping can be performed by any of a number of conventional techniques; e.g., machining, grinding, chemical etching, and so on.

[45] It is noted that the starting substrate material needs not be pre-stressed. However, it can be appreciated that a pre-stressing step can be performed so that when the re-shaping takes place, the stress of the re-shaped substrate can be compensated, either by adding more stress or reducing it as needed for a particular application.

[46] A diamond deposition 922 step is performed to produce a diamond layer 912 atop the substrate. Techniques for forming a suitable coating of diamond are known. As can be expected, the diamond layer will stress the substrate 902 as it crystallizes, thus pulling the pre-shaped form of the substrate 902 into a new shape 902'. It is noted that the final shape need not be a flat surface, though a flat surface may be desirable. It can be appreciated that any desired surface contour can be achieved by properly pre-shaping the starting substrate material and depositing the diamond layer and varying its thickness to obtain a certain degree of re-shaping effect.

It can be appreciated that additional diamond layers can be provided to further effect shaping of the surface contour due to the warping effect of the diamond layers. For example, a diamond coating can be deposited on a first surface of the substrate, followed by another diamond coating deposited on the surface opposite the first surface, to compensate for the warping of the first diamond layer. Selected areas on a first side of substrate can be treated to form one or more diamond coatings at those selected surface areas, to effect control of contour shape.

WHAT IS CLAIMED IS:

1. A cantilever assembly suitable for use in a scanning probe microscope (SPM) comprising a holder and a lever extending from the holder, the lever having a first major surface, the lever further having an end portion distal the holder, the end portion having a recessed region formed on the first major surface.

2. The cantilever assembly of claim 1 further comprising one or more alignment features disposed at the end portion of the lever, the alignment features positioned relative to the recessed region.

3. The cantilever assembly of claim 2 wherein the one or more alignment features are recessed surface features.

4. The cantilever assembly of claim 2 wherein the one or more alignment features are raised surface features.

5. The cantilever assembly of claim 2 wherein the one or more alignment features are a combination of raised and recessed surface features.

6. The cantilever assembly of claim 1 wherein the lever is ventilated.

7. The cantilever assembly of claim 1 wherein the lever includes a second major surface spaced apart from the first major surface and in parallel relation to the first major surface, the lever further including one or more openings formed through the first major surface and the second major surface.

8. The cantilever assembly of claim 1 wherein the holder includes a major surface having at least one recessed feature formed therein, the recessed feature having an opening that at least partially occludes an interior region of the recessed feature.

9. The cantilever assembly of claim 1 having an overall area equal to or less than 3 mm^2.

10. A cantilever assembly suitable for scanning probe microscopy, the cantilever assembly comprising a main body portion and a flexible member integral with the main body portion, the flexible member extending away from the main body portion and

having a free end distal the main body portion, the flexible member having a perforated structure.

11. The cantilever assembly of claim 10 wherein the flexible member comprises a first major surface and a second major surface spaced from the first major surface and parallel to the first major surface, the perforated structure comprising one or more openings formed through the first major surface and through the second major surface of the flexible member.

12. The cantilever assembly of claim 10 further comprising a region in the free end of the flexible member having a recessed area.

13. In a scanning probe microscopy system, a mounting plate having a recessed region configured to receive a first cantilever assembly having first cantilever dimensions and at least a second cantilever assembly having second cantilever dimensions different from the first dimensions, the recessed region comprising a first receiving region having predetermined dimensions based on the first cantilever dimensions, the recessed region further comprising a second receiving region having predetermined dimensions based on the second cantilever dimensions, wherein a position measurement of a cantilever of the first cantilever assembly relative to a reference is the substantially the same as a position measurement of a cantilever of the second cantilever assembly relative to the reference.

14. The mounting plate of claim 13 wherein the position measurement is made relative to a scanning surface.

15. A mounting plate suitable for receiving a cantilever assembly, the cantilever assembly used for scanning probe microscopy, the mounting plate comprising:

a major surface; and

a recess formed in the major surface, the recess comprising first interior surfaces and at least second interior surfaces,

the first interior surfaces configured to receive a first cantilever assembly,

the second interior surfaces configured to receive a second cantilever assembly,

a position of a cantilever of the first cantilever assembly measured relative to a scanning surface when the first cantilever is received by the first interior surfaces being substantially equal to a position of a cantilever of the second cantilever assembly measured

relative to the scanning surface when the second cantilever is received by the second interior surfaces.

16. A fluidic pump comprising a first gear in mesh with a second gear to form a gear assembly, a gear drive coupled to rotate the gears, and a gear assembly housing, the housing having a fluid chamber within which gear teeth of the first gear and the second gear can be exposed to a fluid contained in the chamber, the chamber having a fluid inlet, the housing further having a flow restricted portion in a gear mesh region where the first gear and the second gear mesh, the flow restricted portion having an outlet aligned with the gear mesh region, wherein during rotation of the first gear and the second gear the gear teeth exposed to the fluid in the chamber can carry some of the fluid to the gear mesh region so that the carried fluid can then flow out of the outlet.

17. The fluidic pump of claim 16 wherein the first gear and the second gear each is less that 1 mm^2 in area.

18. The fluidic pump of claim 16 wherein the gear drive includes a gear rack in mesh with one of the gears to convert a linear motion of the gear rack to rotary motion in the gears.

19. The fluidic pump of claim 16 wherein the gear drive comprises one of an electrostatic comb drive, a piezoelectric drive, and a piezoresistive drive.

20. The fluidic pump of claim 16 wherein the first gear and the second gear each comprises a silicon-based material and a low stiction material in contact with the silicon to provide surfaces of the gear teeth.

21. The fluidic pump of claim 20 wherein the low stiction material is diamond.

22. A fluidic pump comprising a fluid chamber, a gear assembly disposed in the fluid chamber, and a gear drive coupled to rotate the gear assembly, the gear assembly comprising a first gear in mesh with a second gear, gear teeth of the gears being exposed to the interior volume of the fluid chamber, the fluid chamber having an opening in alignment with a mesh region where the gears mesh, flow of a fluid from within the fluid chamber to the outlet substantially arising from rotation of the gears wherein the fluid is picked up by the

gear teeth and carried to the mesh region so that the fluid can flow from the mesh region out of the chamber via the outlet, wherein the first and second gears each is less than 1 mm^2 in area.

23. The fluidic pump of claim 22 wherein the first and second gears each has a diamond coating comprising the surface of at least the gear teeth.

25. A tool having a knife edge comprising a substrate, a diamond layer disposed on the substrate, an overcoat layer disposed atop the diamond layer.

26. The tool of claim 25 wherein the overcoat layer comprises one of a tungsten-based compound, a titanium-based compound, a chromium-based compound, silicon, a cobalt-based metal, a nitride metal, and a carbide metal.

27. A tool having a knife edge comprising a first substrate having deposited thereon a diamond layer, a second substrate arranged to sandwich the diamond layer between the first and the second substrates.

28. A method for producing a target surface contour in a substrate comprising providing a substrate, determining warping effects on the substrate due to depositing a diamond layer thereon, forming a compensating surface contour in the substrate based on the warping effects, and depositing a diamond layer on a first surface portion of the substrate, wherein the compensating surface contour of the substrate is altered due to the warping effect.

29. The method of claim 28 further comprising depositing another diamond layer on a second surface portion of the substrate.

30. The method of claim 29 wherein the first and second surface portions are different areas on the same side of the substrate.

31. The method of claim 28 further comprising depositing another diamond layer on a second surface portion of the substrate opposite the first surface portion.

32. The method of claim 28 wherein the first surface portion spans the entirety of a first surface of the substrate.

33. A method for shaping a substrate comprising providing a substrate having a first shape, forming a first diamond layer on a first surface of the substrate to produce a diamond-coated substrate, wherein formation of the first diamond layer causes warping of the substrate to produce a second shape in the substrate.

34. The method of claim 33 further comprising forming a second diamond layer on a second surface of the substrate opposite the first surface, wherein formation of the second diamond layer causes additional warping of the substrate to produce a third shape in the substrate.

35. The method of claim 34 wherein the first shape is substantially planar so that a resulting structure comprising the substrate and the firs and second diamond layers can be planar.

36. The method of claim 33 further comprising forming a second diamond layer on a second surface of the substrate, wherein formation of the second diamond layer during additional warping of the substrate to produce a third shape in the substrate.

37. The method of claim 33 further comprising pre-stressing the substrate, prior to forming a first diamond layer in order to reduce or increase stress in the diamond-coated substrate.

38. A method for forming a layer of diamond comprising producing a substrate having predetermined shape and coating the substrate with a layer of diamond, wherein formation of the diamond layer deforms the substrate, wherein the predetermined shape is selected to compensate for the deformation to produce a target shape in the substrate.

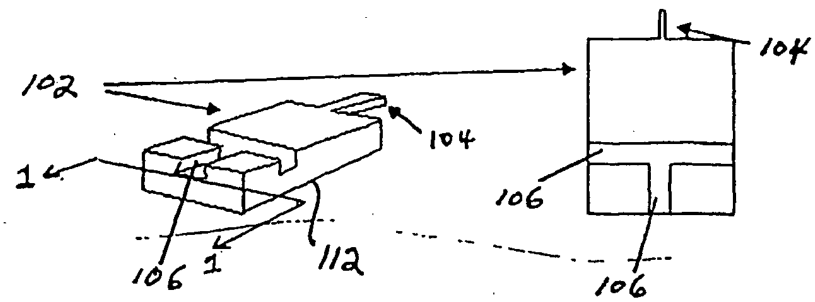


Fig. 1

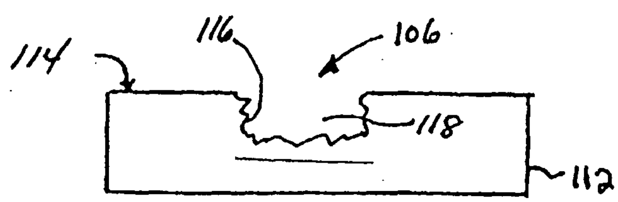


Fig. 1A

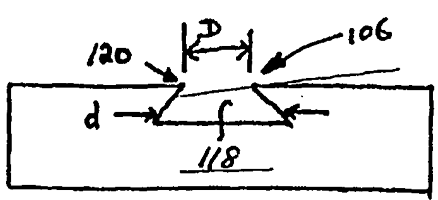


Fig. 1B

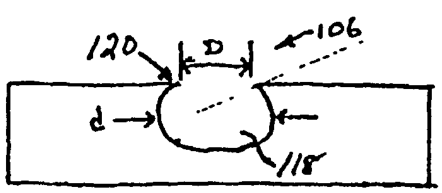


Fig. 1C

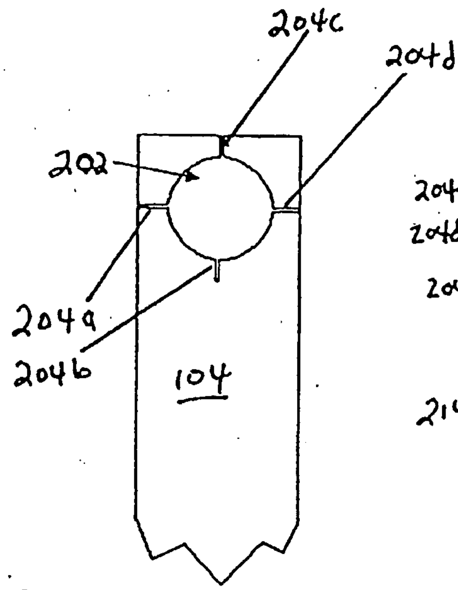


Fig.2

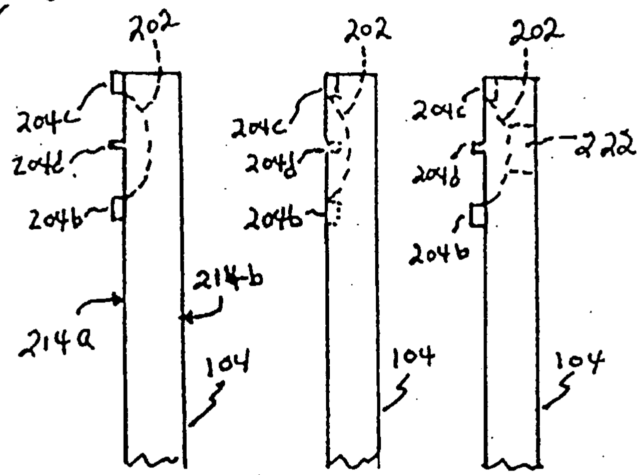
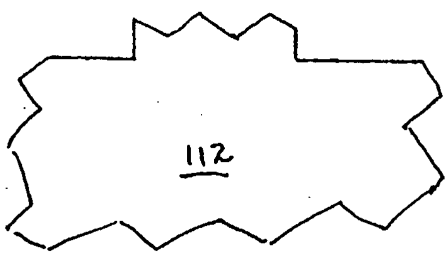


Fig.2A Fig.2B Fig.2C



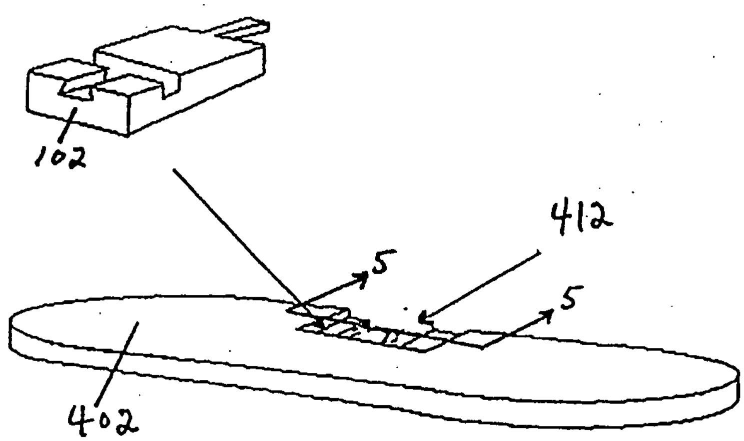


Fig. 4

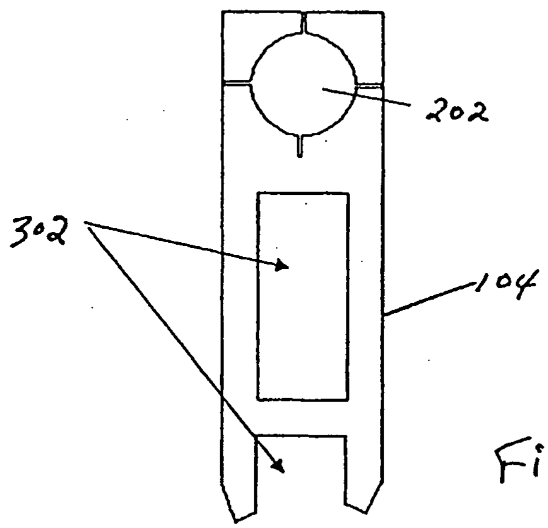


Fig. 3

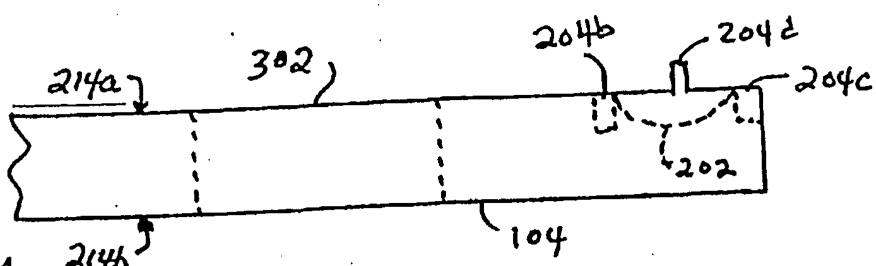


Fig. 3A

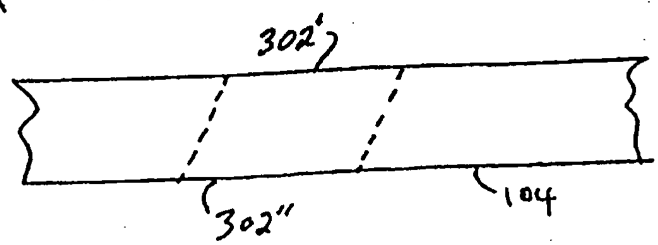
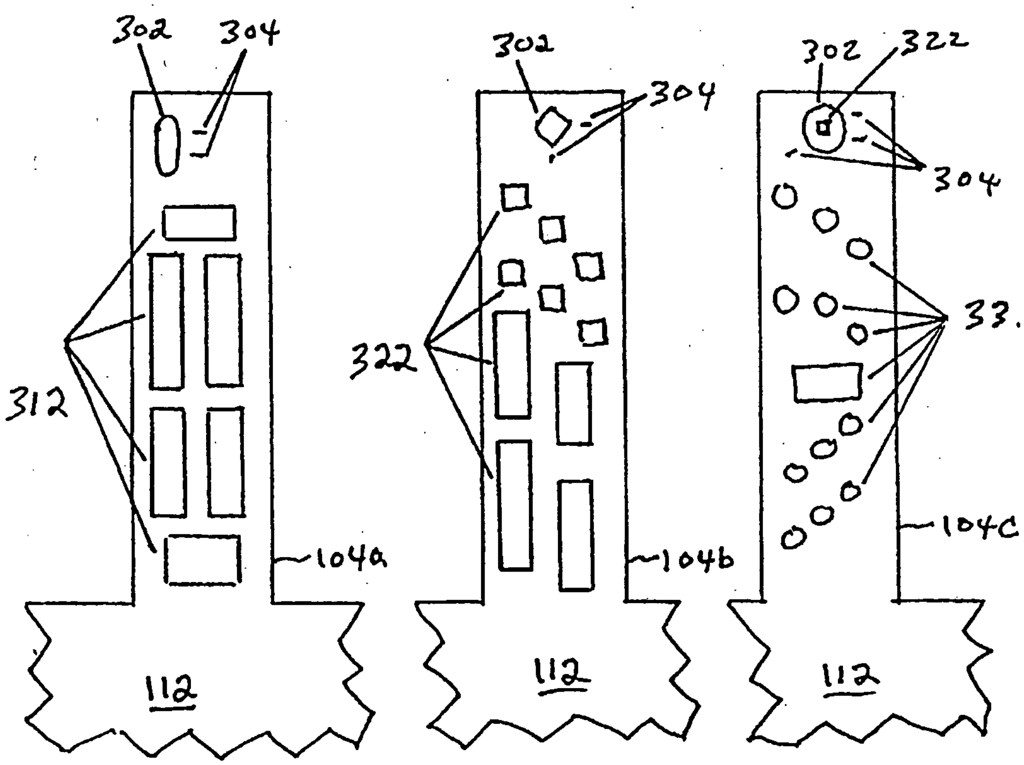


Fig. 3B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104c
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Fig. 3C

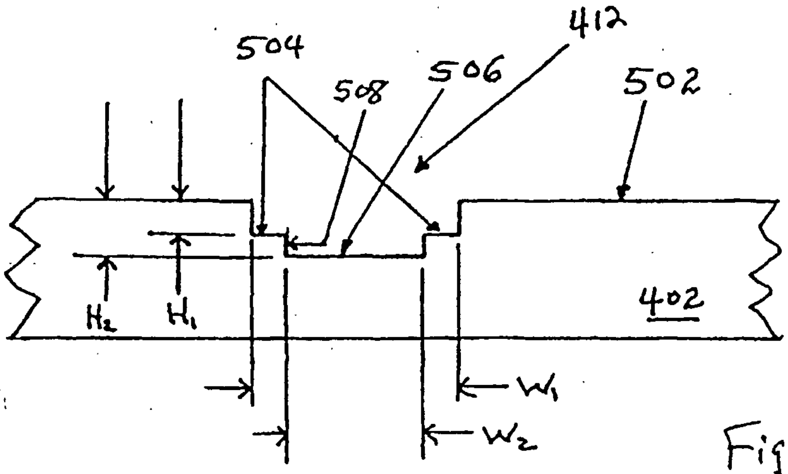


Fig. 5A

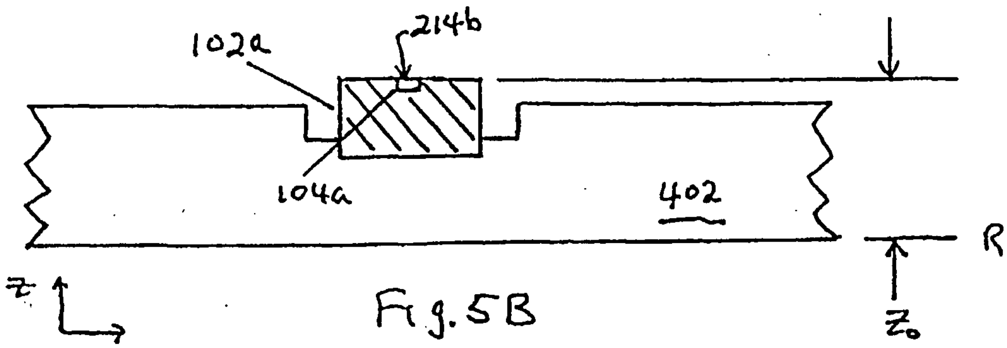


Fig. 5B

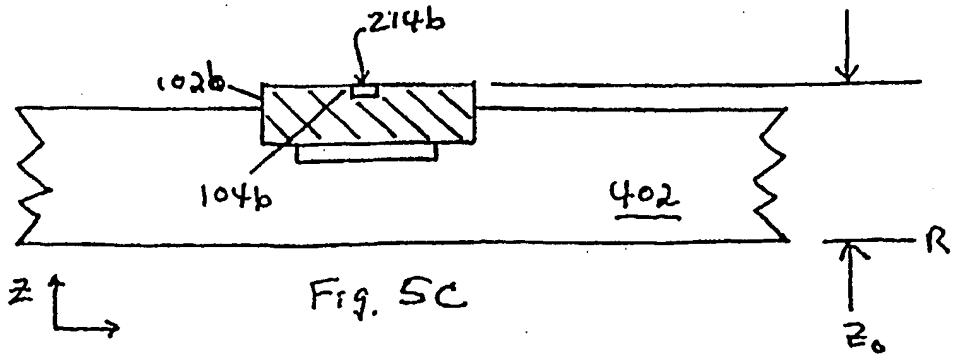
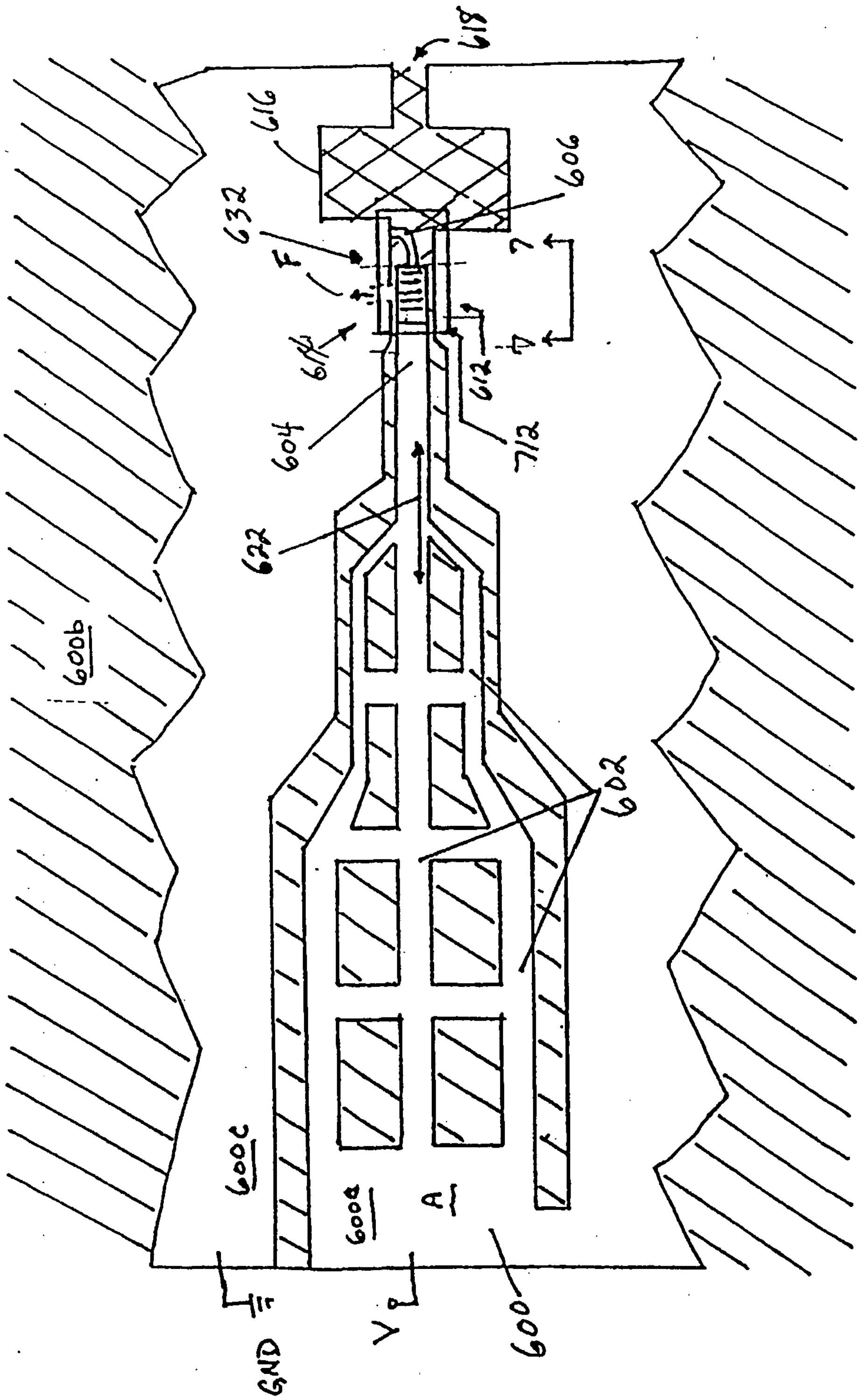


Fig. 5C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600c
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Fig. 6

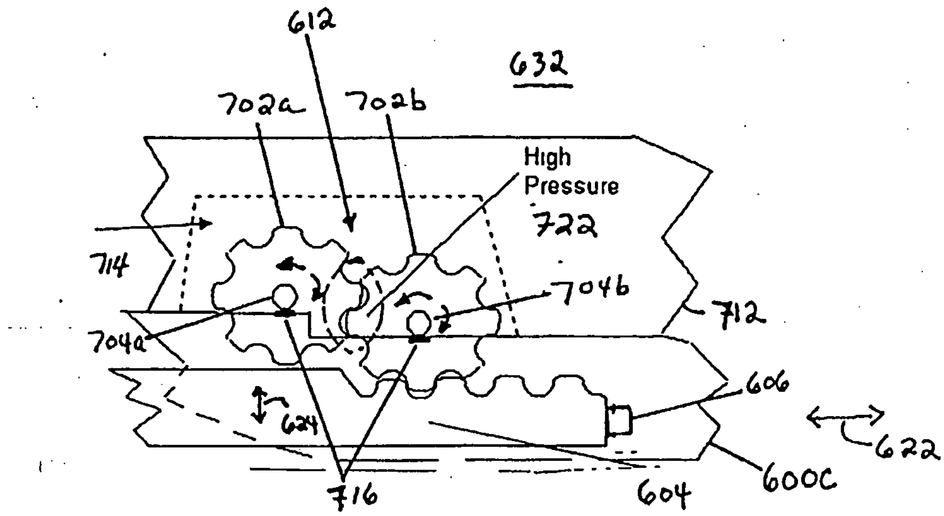
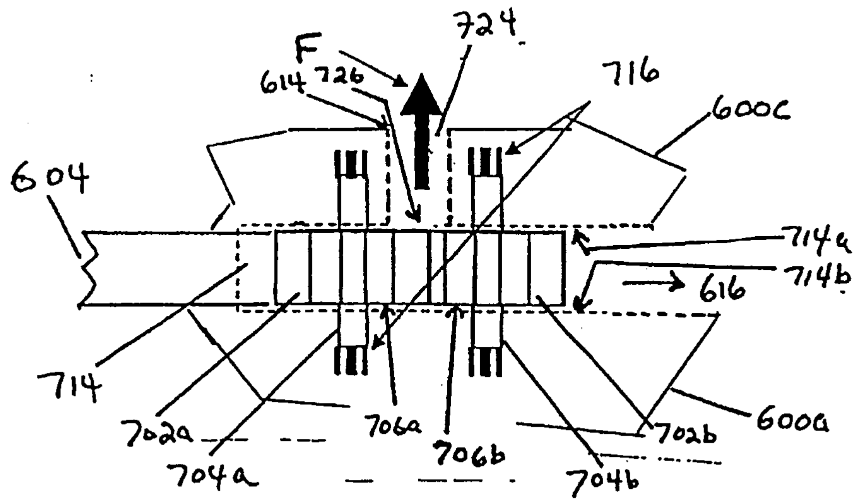


Fig. 7A

Fig. 7B



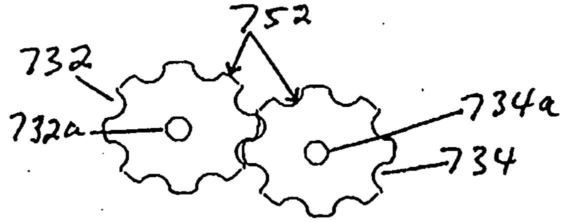


Fig. 7c

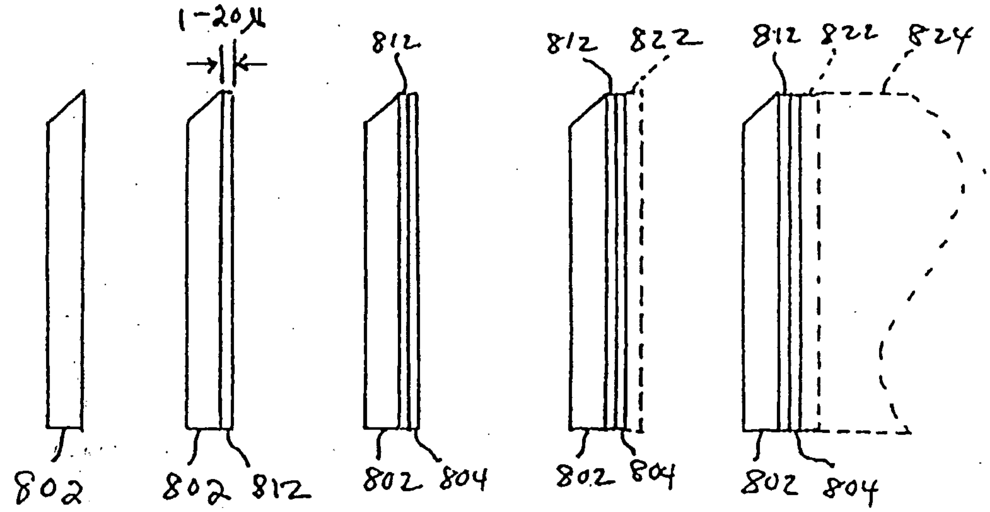


Fig. 8

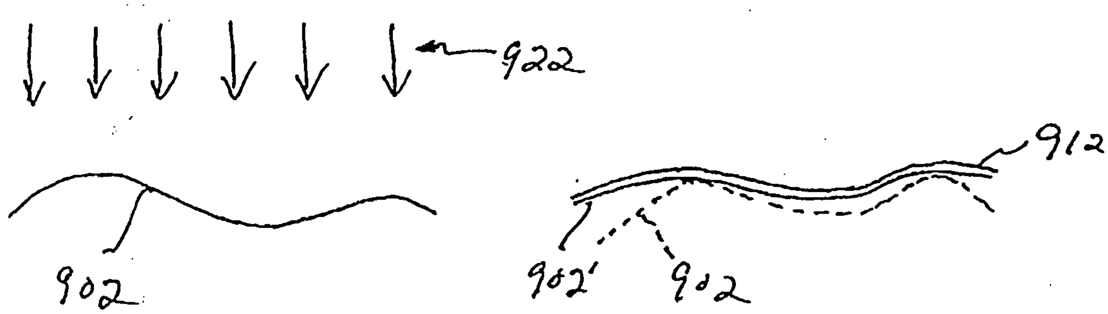


Fig. 9

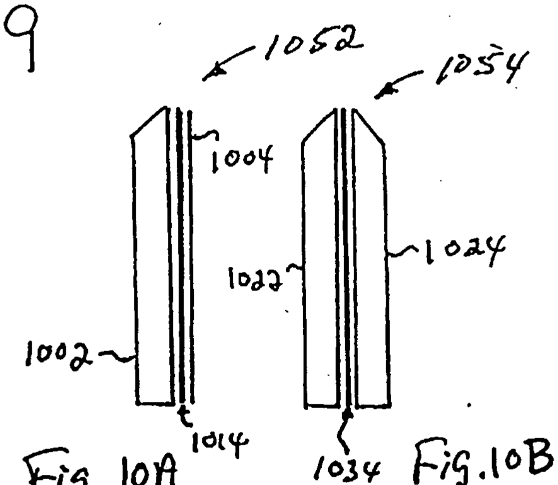


Fig. 10A Fig. 10B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/38036

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G01B 5/28
US CL :73/105
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/105; 250/306, 307

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	JP 1-262403 A (TANAKA) 19 October 1989 (19.10.1989), see CONSTITUTION and Figures 1 and 4.	1 -- 2-7,9
Y	US 5,319,961 A (Matsuyama et al) 14 June 1994 (14.06.1994), see Figure 11.	2-7, 9
A	RASMUSSEN et al., Fabrication of an All-Metal Atomic Force Microscope Probe, IEEE 1997, see Figure 1.	1-9
A	US 5,583,286 A (Matsuyama) 10 December 1996 (10.12.1996), see hole 40.	1-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

11 MARCH 2003

Date of mailing of the international search report

09 APR 2003

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BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Note that originally filed Claims 25-38 were renumbered to read claims 24-37, as claims must be consecutively numbered. The dependencies were also corrected. (For example, renumbered claim 25 (originally, claim 26) now depends upon renumbered claim 24.)

Group I, claim(s)1-9, drawn to cantilever with recessed region.
Group II, claim(s) 10-12, drawn to cantilever with perforations.
Group III, claim(s) 13-14, drawn to scannin probe microscopy system.
Group IV, claim(s)15, drawn to mounting plate with plurality of distinct interior surfaces.
Group V, claim(s) 16-23, drawn to a pump.
Group VI, claim(s) 24, 25, drawn to knife edge with overcoat layer.
Group VII, claim(s)26, drawn to knife edge with two sandwiching substrates.
Group VIII, claim(s) 27-31, drawn to a method to produce a target.
Group IX, claim(s) 32-36, drawn to method for shaping a substrate.
Group X, claim 37, drawn to method for forming a layer.

Group V is independent from the remaining groups, as Group V is directed to a pump while the remaing groups are directed to cantilver assemblies, microscopy, mounting plates, knife edge tools and method to produce a knife edge tool. The, Group V lacks unity of invention.

Groups VI to X are independent from Groups I to IV, and thus lack unity of invention.

Groups VII and VIII lack unity of invention with respect to Groups VIII, IX and X because Groups VII and VIII are directed to tool having a "knife edge" that employ a diamond layer, while Groups VIII, IX and X are directed to methods to produce a target that includes "determining warping effects" (Claim 27 of Group VIII), shape a substrate ("shaping a substrate" of claim 32 of Group IX) and to form a layer by compensating for deformation ("compensate for the deformation" (claim 37 of Group X). The methods do not suggest the "knife edge" special technical relation of either of Groups VII and VIII, and the tools do not suggest the "determing warping effects", "shaping" and "compensating" special technical feater of either of Groups IX or X.

Groups VI and VII lack unity of invention as they are patentably distinct species, as Group VI is directed to an embodiment having "an overcoat layer", while Groupd VII is directed to an embodiment employing sandwiched substrates.

Groups VIII, IX and X lack unity of invention with respect to one another because each of the three methods employ different technical relationships ("determinng warping effects" of Claim 27, "shaping a substrate" of claim 32, and compensating for deformation of Claim 37 as described two paragraphs above.

Group IV lacks unity of invention with respect to Groups I to III because Group IV is directed to a "mountin plate" the employs a plurality of interior surfaces that allows mounting of any structure (for example a probe).

Group III lacks unity of invention with repect to Groups I and II because Group III is directed to a "scanning probe microscopy system" permitting for connections with either of two different cantilevers in such system, necessarily suggestive of a special technical feature.

Groups I and II lack unity of inventin with respect to one another as Group I employs an "end portion having a recess" on a cantilever assembly, whild Group II employs a flexible member having a "perforated structure" in a cantilever assembly. Each of the quoted passages are special technical features not found the other of the two groups.